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RADIOLOGICAL PROTECTION FROM RADIOACTIVE WASTE MANAGEMENT IN EXISTING EXPOSURE SITUATIONS RESULTING FROM A NUCLEAR ACCIDENT

Daisuke Sugiyama* and Takatoshi Hattori
Radiation Safety Research Center, Nuclear Technology Research Laboratory, Central Research Institute of Electric Power Industry (CRIEPI), 2-11-1 Iwado-Kita, Komae, Tokyo 201-8511, Japan

*Corresponding author: daisukes@criepi.denken.or.jp

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In environmental remediation after nuclear accidents, radioactive wastes have to be appropriately managed in existing exposure situations with contamination resulting from the emission of radionuclides by such accidents. In this paper, a framework of radiation protection from radioactive waste management in existing exposure situations for application to the practical and reasonable waste management in contaminated areas, referring to related ICRP recommendations was proposed. In the proposed concept, intermediate reference levels for waste management are adopted gradually according to the progress of the reduction in the existing ambient dose in the environment on the basis of the principles of justification and optimisation by taking into account the practicability of the management of radioactive waste and environmental remediation. It is essential to include the participation of relevant stakeholders living in existing exposure situations in the selection of reference levels for the existing ambient dose and waste management.

INTRODUCTION

Since the accident at the Fukushima Dai-ichi nuclear power plant hit by the magnitude-9.0 earthquake and the subsequent great tsunami of 11 March 2011, large quantities of radionuclides have been released outside the damaged reactors and have contaminated a large area around the plant. In the environmental remediation (e.g. decontamination of land) in the contaminated area, the generation of radioactive wastes that have to be appropriately managed under the concept of radiological protection is inevitable and should be regarded as an integral part of the remediation process.

The currently available radiological protection system for radioactive waste management (e.g. in ICRP Publication 77[1] and Publication 81[2]) has been constructed basically only for planned exposure situations with a normal background radiation dose level, in which compliance with the dose limit of 1 mSv y^{-1} for public exposure is demonstrated. In view of the principle of optimisation taking social and economic factors into account, it is not absolutely practical and reasonable to apply the available system in planned exposure situations to remediation in contaminated areas because the radiation level in existing exposure situations would be reduced using the reference level selected from a band of more than the order of 1 mSv y^{-1}, which is higher than the dose limit of 1 mSv y^{-1} in planned exposure situations. In some instances, it may even retard the execution of remediation actions.

In this paper, a framework of radiological protection from radioactive waste management in existing exposure situations is proposed. Key issues for establishing a framework of radiological protection for radioactive waste management in existing exposure situations are discussed, referring to some related ICRP recommendations. The application of the proposed concept to the case of environmental remediation after the accident at the Fukushima Dai-ichi nuclear power plant is also discussed.

FRAMEWORK OF RADIOLOGICAL PROTECTION FROM RADIOACTIVE WASTE MANAGEMENT IN EXISTING EXPOSURE SITUATIONS

Fundamental concept for existing exposure situations in ICRP recommendations

Situations that may cause prolonged radiation exposure resulting from contamination by released radionuclides from nuclear accidents or radiological events are recognised as existing exposure situations in ICRP Publication 103[3].

ICRP Publication 82[4], which recommends the radiological protection of the public in situations of

prolonged radiation exposure due to long-lived radioactive residues, provides the guideline that an existing annual dose (all of the existing and persisting whole annual doses incurred by individuals in a given location) higher than ~10 mSv may justify intervention to reduce the dose on a case-by-case basis; if intervention is considered justifiable, protective actions (form, scale and duration) should be optimised by taking all related factors into account, including the avertable annual doses. Publication 82 also recommends a generic intervention exemption level of around 1 mSv y^{-1} for the individual dose expected from a dominant type of commodity amenable to intervention.

ICRP Publication 103 describes the exposure situations (planned, emergency and existing exposure situations) and radiological protection in each situation, whereas ICRP Publication 111[5] describes the protection of people living in long-term-contaminated areas after a nuclear accident. Publication 103 says that there is a desire from both the exposed individual and the authorities to reduce exposures to levels that are close to or similar to situations considered as normal in most existing exposure situations. The concept of the reference level, which is the source-related restriction to the dose that individuals may incur, is used as a tool in the optimisation of protection to ensure that all exposures are kept as low as reasonably achievable taking into account societal and economic factors. Publication 111 says that the reference level for the optimisation of protection of people living in contaminated areas should be selected from the lower part of the dose band of greater than 1 mSv y^{-1} but not more than 20 mSv y^{-1} recommended in Publication 103.

According to those recommendations, the environmental remediation should be aimed at reducing existing annual dose to or below the order of 1 mSv y^{-1} which corresponds to the normal dose level (natural background exposure causes annual doses of at least a few millisieverts per annum[4]) in the longer term using a reference level selected in the lower part of the 1–20 mSv y^{-1} dose band as a tool for optimisation in existing exposure situations that may involve several exposure pathways and may give rise to annual individual doses ranging from very low to several tens of millisieverts. If the existing annual ambient dose is reduced to a certain level corresponding to the normal background level as the remediation proceeds, intervention may be exempted.

It should be noted that ICRP recommends the participation of the stakeholders in the decision-making process. Publication 82 and Publication 111 say the participation of relevant stakeholders in the decision-making process is essential. Publication 111 also states that the process of selecting the value of the reference level should also be carefully balanced to appropriately include the views of all relevant stakeholders.

Radioactive waste management in existing exposure situations

In areas contaminated with radioactive materials under existing exposure situations, remediation activities will be carried out to reduce the annual individual doses. In decontamination, substances contaminated with radionuclides (e.g. contaminated soil) will be removed and collected, and regarded as radioactive wastes. In the Fukushima case, the collected radioactive wastes will first be stored temporarily in the vicinities of the contaminated areas and then transported to longer-term storage and appropriate processing if required, prior to disposal. The generation of radioactive wastes is inevitable in decontamination; in other words, the management of radioactive wastes (in this paper, the term 'management of radioactive waste' covers all the steps from its generation up to disposal, including processing and storage, except transportation) must be regarded as an integral part of the strategy to reduce the existing annual dose in remediation under existing exposure situations. A framework of radiological protection for radioactive waste management in existing exposure situations should be established to make such waste management reasonably practical, since the radiological protection for the management of radioactive waste, including disposal, in existing exposure situations has not been definitely discussed previously as mentioned above.

The management of radioactive wastes could be justified when the net benefit was positive; the individual dose was substantially reduced by the waste management in the existing exposure situation. Then, the averted existing ambient dose by decontamination should be optimised by taking the potential exposure from the accompanying radioactive waste management into account. In view of radiological protection from radioactive waste management, the reference level for the additional dose attributable to radioactive waste management should be selected as a source-related restriction. Since radioactive waste management will be carried out to reduce the existing annual dose, the reference level for radioactive waste management should be selected below the reference level for the existing annual ambient dose in circumstances under existing exposure situations. In the planning and execution of radioactive waste management, it is appropriate to ensure that the estimated dose from radioactive waste management does not exceed the selected reference level because it is a potential exposure.

Figure 1 conceptually shows the relationship between the estimated exposure from radioactive waste management and the averted existing ambient dose by remediation that produces wastes. In remediation, the existing dose will be reduced progressively if the estimated dose from waste management is less

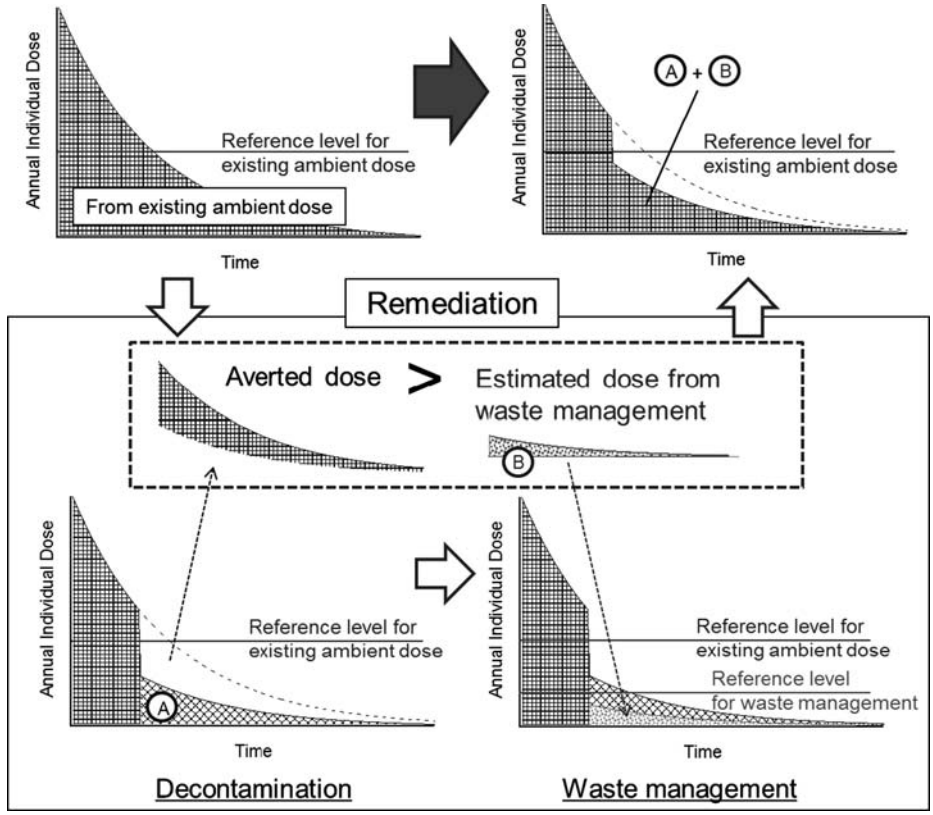

Figure 1. Relationship between the estimated dose from radioactive waste management and averted existing ambient dose in remediation using reference levels (modified from Sugiyama and Hattori[6]).

than the averted dose by selecting the reference level for waste management below the reference level for the existing ambient dose.

The disposal of radioactive waste as a final step in waste management should be appropriately carried out so that no further active control is necessary after the closure of the repository. As part of the integrated strategy to reduce the existing annual ambient dose to or below the order of 1 mSv y^{-1} in the environment that corresponds to the normal dose level, therefore, it would be appropriate that the final target reference level of the source-related dose restriction attributable to the radioactive waste disposal is set at an equivalent level to the generic intervention exemption level recommended in Publication 82.

In this context, it is emphasised that the dose from radioactive waste management should be gradually reduced by selecting the intermediate reference levels under existing exposure situations. If a single target value (e.g. 1 mSv y^{-1}) is applied to all the processes of radioactive waste management, there is some concern in environmental remediation that the reduction in the existing ambient dose will not go well or will proceed late owing to the limitation of decontamination, and the plan of waste management may be made economically and technically impractical. Therefore, it is concluded that the intermediate reference levels should be selected progressively down to the final target according to the progress of remediation process on the basis of the fundamental principle of optimisation: the individual doses should be kept as low as reasonably achievable taking economic and social factors into account. A reference level of 1 mSv y^{-1} may be used as a target value in the decision regarding the final closure of the repository.

Stakeholder involvement

It is essential to establish environmental remediation plans including waste management together with relevant stakeholders living in existing exposure situations to carry out activities for reducing the individual annual dose. It is important to substantially understand the concept of optimisation that the averted dose by decontamination should be balanced

by the potential exposure from the accompanying radioactive waste management. Under these circumstances, it is appropriate to select gradual intermediate reference levels for the existing annual ambient dose and for waste management according to the progress of the reduction in the individual doses in the integrated plan of environmental remediation. The participation of stakeholders should be strongly recommended in the decision-making process.

Proposal of framework of radiological protection from radioactive waste management in existing exposure situations

On the basis of the discussion above, a framework of radiological protection from radioactive waste management in existing exposure situations is proposed as follows:

(1) The reference level for radioactive waste management as a source-related restriction is selected below the reference level chosen for the existing annual ambient dose in the environment.
(2) Intermediate reference levels are adopted gradually according to the progress of the reduction in the existing ambient dose in the environment by taking into account the practicability of the management of radioactive waste and remediation including the participation of stakeholders.
(3) In the planning and execution of radioactive waste management, it is ensured that the estimated dose from radioactive waste management does not exceed the selected reference level.
(4) If the existing annual ambient dose and the reference level for waste management are reduced to a certain level corresponding to the normal background level as the remediation proceeds, intervention can be exempted.
(5) A reference level of 1 mSv y^{-1} may be used as a target value in the decision regarding the final closure of the repository.

APPLICATION OF THE PROPOSED CONCEPT TO ENVIRONMENTAL REMEDIATION AFTER FUKUSHIMA NUCLEAR ACCIDENT

In this section, the application of the proposed concept to environmental remediation after the accident at the Fukushima Dai-ichi nuclear power plant is discussed. The radiation dose rate in air in some areas around the damaged nuclear power station was >100 μSv h^{-1} in the early stage after the accident and the estimated annual dose was more than several hundred millisieverts[7]. Dominant radionuclides in the contaminated area after the accident at the Fukushima Dai-ichi nuclear power plant are ^{137}C and ^{134}Cs[8]; their existing annual dose in the environment will decrease to less than about 1/100 after 150 y and then to 1/1000 in 250 y owing to their natural decay, and the residual existing annual dose will then decrease to levels similar to that in normal situations. In radiological protection strategies for radioactive waste management, the decay (half-life) of the radionuclides concerned should be taken into account.

On the basis of the discussion above, radioactive waste management in existing exposure situations under institutional control (e.g. land use controls, prevention of public access to the site) should be planned and executed to ensure that the individual doses assessed from waste management using a concept of a representative person[9] do not exceed the reference level selected below the reference level for the existing annual ambient dose in the environment.

Management of wastes contaminated with ^{137}Cs and ^{134}Cs

The radiation dose from the wastes contaminated with ^{137}Cs and ^{134}Cs will decrease with time, as the existing annual ambient dose in the environment decreases, owing to the decay of those radionuclides. In the case that the dominant exposure pathway is direct external exposure (including skyshine exposure) from radioactive wastes, the wastes could be managed so that their estimated individual dose would not exceed the selected reference level by the appropriate planning and operation of the facilities including shielding measures.

Figure 2 illustrates the concept of reduction in annual individual dose in environmental remediation including waste management in existing exposure situations. Under an existing exposure situation with a certain ambient dose, the first reference levels for the existing annual ambient dose and for waste management are selected. It is noted that the reference level for the radioactive wastes should be selected as a source-

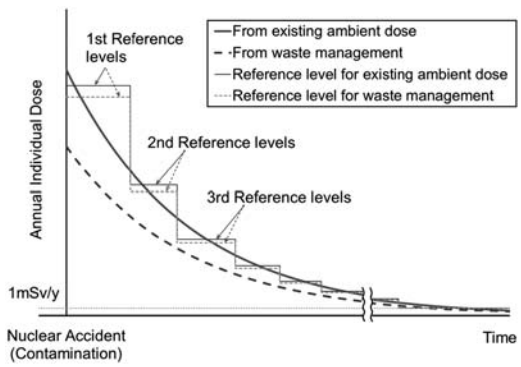

Figure 2. Conceptual diagram of reduction in individual dose in existing exposure situations.

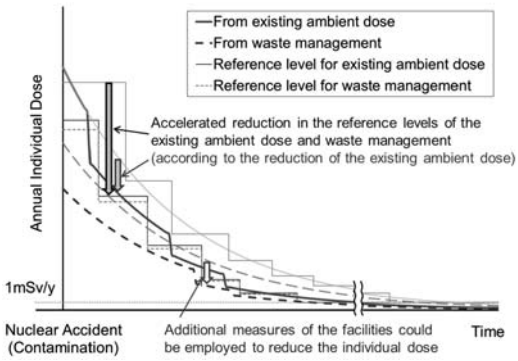

Figure 3. Conceptual diagram of reduction in individual dose in existing exposure situations (accelerated remediation case).

related restriction to make waste management reasonably practical. When the existing annual ambient dose is reduced to below the first reference level, the second reference levels for the existing annual ambient dose and for waste management are selected to be lower than the first values. This procedure is repeated until the existing annual ambient dose in the environment is reduced to the normal dose level.

If the remediation activities (e.g. an extended decontamination) were set to reduce the existing annual ambient dose and the reference level for the existing annual ambient dose was moved lower than expected, the reference level for waste management would have to be reduced accordingly. In the operation stages of the storage and reprocessing of wastes, additional measures of planning and operating the facilities could be employed to reduce the estimated dose (Figure 3).

In the post closure period of the waste repository, the dominant exposure would be given by the groundwater scenario, where radionuclides transported by flowing groundwater contribute to the dose concerned, since there is continuous institutional control to prevent living in the site just above the disposal facility in existing exposure situations. In this case, the closure of the repository could be planned and executed to ensure that the estimated maximum dose does not exceed the final target reference level of 1 mSv y^{-1}. The dose from the wastes disposed will decrease with time and the residual existing annual dose will decrease to a level that is similar to that in normal situations.

Management of wastes contaminated with the long-lived radionuclides

In the disposal of long-lived radioactive wastes, a certain extent of dose would remain although the residual doses from ^{137}Cs and ^{134}Cs decrease for a long period of time to a level similar to that in the normal situations owing to the decay of these radionuclides in the contaminated areas. Even in this case, it should be possible to manage wastes below the selected reference levels with reasonable planning and operation of the facilities, prior to the closure of the disposal facility.

In the post-closure period, the maximum dose from long-lived radioactive wastes may be estimated to occur when the environmental dose level is expected to be on the order of 1 mSv y^{-1} equivalent to the normal background dose level. In this case, therefore, it may be appropriate for the long-term assessment (after several thousands to several tens of thousands of years) with certain uncertainties to harmonise the concept of radiological protection with that of the disposal of long-lived radioactive wastes in planned exposure situations provided in ICRP Publication 81; the dose constraint of 0.3 mSv y^{-1} is recommended for long-lived radioactive waste disposal as the individual source-related constraint for the public.

SUMMARY

A framework of radiation protection from radioactive waste management in existing exposure situations is proposed, in which intermediate reference levels for such waste management are adopted gradually according to the progress of the reduction in the existing annual ambient dose in the environment to or below the order of 1 mSv y^{-1} that corresponds to the normal dose level. A reference level of 1 mSv y^{-1} may be used as a target value in the decision regarding the final closure of the repository. The intermediate reference levels should be selected to make the remediation activities reasonably practical on the basis of the principle of justification and optimisation including the participation of relevant stakeholders living in existing exposure situations, with considerable appreciation of integrated environmental remediation strategies including waste management.

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